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Expression and Performance of Nepalese Wheat Genotypes under Irrigated and Multiple Abiotic Stress Conditions

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ABSTRACT

Background: The wheat crop plays a crucial role in Nepal's agricultural economy. This study aims to evaluate the performance and stability of various wheat genotypes under different environmental conditions, with the goal of identifying the most stable and adaptable genotype.

Methods: The experiments was conducted across five environments using 20 wheat genotypes in alpha lattice design with two replications at Bhairahawa, Nepal.

Result: The most significant yield reduction, of 86.37%, occurred under drought conditions compared to irrigated ones, where NL_1447 recorded the highest yield of 5943 kg/ha under irrigated conditions. The average yield of wheat genotypes under irrigated,rainfed,drought,heat stress rainfed and heat stress irrigated environments were 4770,1520,650,1952 and 3049 kg/ha, respectively. Analysis of variance indicated that grain yield variation was significantly explained by genotype, environmentand genotype ×environment interaction, accounting for 2.27%, 91.6% and 6.1%, respectively. NL_1504 was particularly well-suited to irrigated conditions, NL_1488 to heat stress irrigated conditionsand Bhrikuti to heat stress rainfed conditions.

Key words: AMMI model, Adaptability, Climate Change, G×E interaction.

INTRODUCTION

Wheat is globally recognized as the primary staple cereal crop, while in Nepal it is the third most important crop in both production volume and cultivated land area (Chaudhary *et al*., 2023). It is a highly nutritious food comprising approximately 60-70% starch, 6-26% protein, 2.7% fibers, 2.1% minerals, 2.1% fat and vitamins (Thapa *et al*., 2022). Currently, wheat cultivation covers an area of 716,978 ha, with average production and productivity of 2,144,568 Mtons and 2.99 mt ha^{-1}, respectively. The crop solely accounts for 6.34% of Agricultural Gross Domestic Product (AGDP) and 5.67% Gross Domestic Product (GDP)(MoALD, 2023).The cultivation of wheat is more susceptible to heat stress, drought and high temperatures. Drought stress lowers the wheat crop's soluble sugar, protein content and starch content (Pampana *et al*., 2022). Wheat experiences terminal heat stress during anthesis and grain filling when temperature exceed 25°C, which results in yield reduction. The longer the exposure to heat stress, the higher the loss in wheat yield (Bishwas *et al*., 2021). 1°C increase in temperatures over the cropping season could reduce 5.6% production of wheat yield (Djanaguiraman *et al*., 2020).

Changes in climate have an adverse effect on the quality of wheat grains, especially on their protein content and sugar and starch percentages (Pampana *et al*., 2022). Thus, one of the most efficient long-term adaptation techniques for climate change is the development of new genetic cultivars that are resistant to abiotic stress and capable of being utilized at periods of optimal rainfall and temperature (Poudel *et al*., 2023a), Mullaivendhan *et al*., 2024). Although adaptation strategies have shown some positive effects, they have not been enough to overcome negative effects in most of the countries (Pequeno *et al*., 2021). Lack of water and genetic make-up are the main factors preventing wheat from being cultivated in Nepal (Poudel *et al*., 2024). The strategy to deal with the rising desertification and increase food production is the development of high yielding varieties resistant to diverse biotic and abiotic stressors (Bhusal *et al*., 2022; Poudel and Poudel, 2016). The production of HS-tolerant wheat genotypes can be made possible through molecular breeding and conventional breeding techniques, which screen and select germplasm. The introduction of these cultivars in non-conventional areas will help to address the problem of food and nutritional security (Yadav *et al*., 2022). In Nepal, where agroclimatic conditions vary greatly

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from the Terai to the Himalayas, analysing the stability of diverse lines is crucial (Timalsina *et al*., 2023; Poudel *et al*., 2015). Environmental factors have been regarded as the basis for measuring genetic stability. Genotype-Environment Interaction (GEI) is the result of a crop genotype's sensitivity to environmental factors (Poudel *et al*., 2024). The various methods of graphical and numerical stability can be used to examine the degree of genotype-environment (G × E) interaction and find genotypes which exhibit stability and high seed yields under different environmental conditions (Medik, 2023; Bendada *et al*., 2024). Therefore, the objectives of this study is to examine the GEI for grain yield , utilizing various stability techniques, such as AMMI, BLUP, parametricand non-parametric analysis and to determine the relationships between the different stability techniques.

MATERIALS AND METHODS

Field experimentation

The field experiment was conducted at the Institute of Agriculture and Animal Science (IAAS), Paklihawa, located at 27°30' N, 83°27' E and 79 m above sea level, under five different environments *i.e*. irrigated, rainfed, heat stress rainfed, heat stress irrigated and drought.

Twenty different wheat genotypes (Table 1) were evaluated under Irrigated, rainfed, droughtand heat-stress irrigated and rainfed condition using an alpha lattice design, comprising five blocks and four plots, each replicated twice, with the plot dimension of 2.5 m × 2 m. The Inter-blocks were spaced at 1 m distance while spacing of intra-block and inter-replicates were 50 cm and 1 m meter respectively.

Table 1: List of genotypes.

Entry no.	Genotypes	Origin
1	BL_5106	Nepal
2	BL_5099	Nepal
3	BL_4984	Nepal
4	Bhirkuti	Nepal
5	NL_1437	Mexico
6	NL_1402	Mexico
7	Gautam	Nepal
8	BL_5116	Nepal
9	NL_1492	Mexico
10	NL_1488	Mexico
11	NL_1447	Mexico
12	NL_1445	Mexico
13	NL_1506	Mexico
14	NL_1504	Mexico
15	NL_1503	Mexico
16	NL_1501	Mexico
17	RR_21	Nepal
18	NL_1512	Mexico
19	NL_1509	Mexico
20	NL_1508	Mexico

Seeds were sown in 10 continuous rows spaced 25 cm apart.

In irrigated conditions, irrigation was provided at six critical stages (before sowing, CRI, tillering, booting, post flowering, soft dough) in accordance with the NARC recommendation. Conversely, rainfed condition relied solely on atmospheric rainfall as artificial irrigation was prevented. Drought conditions were induced by covering research field by polythene tunnel to prevent rainfall, moisture and precipitation. Heat stress rainfed and heat stress irrigated condition were created by sowing the wheat genotype one month later (26th December) than the normal condition (25th November). The combined analysis of variance (ANOVA) was performed by using (IBM SPSS Statistics Version 20.0). The stability analysis of the genotypes was performed using additive main effect and multiplicative interaction (AMMI) while GGE biplot analysis was done by using GEAR.

RESULTS AND DISCUSSION

The mean grain yield (GW) for irrigated, rainfed, drought, heat stress rainfed and heat stress irrigated condition was 4770.05 kg/ha, 1520.48 kg/ha, 650.12 kg/ha, 1952.22 kg/ha and 3049.43 kg/ha respectively. Under normal irrigated condition, NL_1447 had highest mean grain yield (GW) (5943.5 cm)and NL_1488 (3708.5 kg/ha) had lowest mean grain yield (GW). Similarly, under rainfed and drought conditions, the maximum grain yield (GW) were found in genotypes NL_1492 (1767.32kg/ha) and NL_1445 (881.55 kg/ha), respectively, while the minimum were in NL_1445 (1272.99 kg/ha) and BL_5099 (481.6 kg/ha). Also, under heat stress rainfed and heat stress irrigated condition maximum grain yield (GW) was observed in genotype NL_1501 (2101.32 kg/ha) and NL_1509 (4200 kg/ha) while minimum grain yield (GW) was observed in genotype NL_1445 (1843.61 kg/ha) and NL_ 1445(2153.5 kg/ha) respectively (Table 2). Drought conditions severely affect meiosis and anthesis during early microspore stage of pollen production, causing pollen sterility, leading to a reduced grain number and ultimately lowering grain yield. The decrease in grain yield was attributed to diminished kernel growth, which was influenced by two factors: the severity of water stress and the rate at which the stress developed. A significant portion of energy produced by wheat plant is directed toward root growth to find moisture in the soil. This leads to the notable reduction in biomass during the tillering and booting stages, ultimately causing a significant reduction of yields (Poudel *et al*., 2023 a). The drought affects the plant height mainly in the stretching phase thus resulting in lower height in wheat plants .Heat and drought stress disrupt reproductive processes, primarily affecting ovule fertility, pollen viabilityand other related factors (Teja *et al*., 2024). High temperatures during meiosis reduce the grain number per spike by causing ovule and pollen sterility and preventing the anthers to release pollen. During the critical flowering stage, physiological processes are adversely impacted by water stress, leading to reduced spikelet fertility. The reduction in thousand-grain weight and then grain yields can be attributed to uneven nutrient absorption efficiency and the movement of photosynthesis within the plant, leading to smaller and shriveled grains due to accelerated maturity. This rapid maturity is likely caused by a lack of moisture, compelling the plant to complete grain development in a shorter period (Poudel *et al*., 2020).

Percentage reduction of yield and yield attributing parameter of wheat

The reduction in plant height in heat stress irrigated condition as compared with normal irrigated condition was 3.13%. Under Heat stress (HS) conditions, whether irrigated or rainfed condition, protein synthesis and folding ceases, causing immediate disruption to the main metabolic processes, including transcription, mRNA transport, translationand DNA replication, untill the cell recovers (Poudel *et al*., 2020b). The reduction of grain yield in heat stress irrigated and rainfed condition was 36.07% and 59.07% respectively (Table 3). Heat stress also affects the wheat grain number and pollen fertility. Under normal irrigated condition, the reproductive stage occurs 40-50 days after sowing but the heat stressed irrigated condition shortens this period causing abnormal development such as reduction in plant height, spike length, spike weight and overall yield (Poudel *et al* 2023c).

Drought stress hinders ovule function, grain weight and pistillate flower development (Vedi *et al*., 2022). The combined effects of heat stress and drought can have antagonistic, synergistic, or hypo-additive effects on grain filling, growthand yield parameters (Vedi *et al*., 2022). Drought stress lowers Gs, PSII reaction centersand the

Table 2: Mean grain yield/ha at stress and non-stress condition.

Genotype	I	R	D	HSR	HSI	Overall
BL_5106	4764	1396.64	561.7	2044.27	3183	1765.02
NL_1488	3708.5	1587.19	701.2	2042.47	3186	1813.35
NL_1447	5943.5	1627.11	705	1980.01	3574.5	1782.59
NL_1445	4964	1272.99	881.55	1843.61	2163.5	1617.5
NL_1506	4996.5	1419.64	786.8	1953.83	2612	1717.03
NL_1504	5542.5	1710.05	713.4	1887.24	2345.5	1739.23
NL_1503	5484.5	1433.23	707.15	1976.11	2548	1734.18
NL_1501	4409.5	1554.74	633.2	2101.32	3907	1840.56
RR_21	4070.5	1497.32	708	1955.27	2636	1728.53
NL_1512	4618	1500.9	691.5	1969.32	3393.5	1738.24
NL_1509	5381	1417.74	657.1	1911.68	4200	1683.23
BL_5099	5040	1547.6	481.6	1890.16	2216	1700.76
NL_1508	4382	1487.85	576	1929.76	2709	1710.25
BL_4984	4964.5	1685.25	523.1	1952	2778	1770.53
Bhirkuti	3925.5	1360.31	516.7	1913.78	3175.5	1674.19
NL_1437	4567.5	1346.26	580.1	1936.61	3146.5	1687.66
NL_1402	4666.5	1674.27	748.15	1913.48	2685	1745.77
Gautam	4544.5	1706.77	700.9	1855.7	3622.5	1716.33
BL_5116	4680	1416.36	631.7	1959.88	3283.5	1717.98
NL_1492	4748	1767.32	497.6	2027.8	3623.5	1844.01
grand mean	4770.05	1520.48	650.12	1952.22	3049.43	1736.35
LSD	2698.5	479.19	759.58	451.67	1849.12	328.04
CV	23.63	19.19	39.14	25.42	26.55	23.55

Where, I= Irrigated condition, D= Drought condition, R= Rainfed condition, HSI= Heat stress irrigated, HSR= Heat stress rainfed.

Table 3: Percentage reduction of yield and yield attributing parameter of wheat studied under heat stress irrigated(HIS), heat stress rainfed(HSR), drought(D) and rainfed(R) compared to irrigated(I).

	Ph	SL	SPS	SW	TGW	TPM	YLD
I- HSI	3.13	3.74	-0.25	9.58	17.22	19.5	36.07
I- HSR	21.51	14.53	17.43	21.4	14.01	34.74	59.07
I-D	18.97	18.98	25.99	55.39	37.42	60.34	86.37
I-R	14.83	13.55	16.56	30.66	19.83	33.95	68.12

Where, Ph=plant height, SL= spike length, SPS= no of spikelet per spike, SW= spike weight, TGW= thousand grain weight, TPM= tiller per m^2, YLD= grain yield.

amount of excess energy exposed in the chloroplasts, all of which limits photosynthesis (Pour-Aboughadareh *et al*., 2020). As a result, grain yield was reduced by 86% and 68% under drought and rainfed environments as compared with irrigated environments (Table 3).

AMMI model

In AMMI model, the 91% variation was explained by environments followed by G*E with 6% and the least variation was explained by Genotypes with 2% (Table 4). The first three PCs explained more than 98% with PC1 ranked highest value with 51.81% followed by PC2 with 28.01% and PC3 with 18.5%.The lines with the lowest PC scores demonstrate greater stability, whereas those with higher scores suggests lower stability (Bishwas *et al*., 2021). PC 1 and PC 2 scores are utilized to assess the stability of the lines across different environmental conditions. NL_1501 ranked as the most stable wheat genotype based on its PC1 score of -0.729022, followed by NL_1488, Bhirkutiand NL_1492, with scores of -0.69122, -0.45805and 0.34125, respectively. While the PC2 score showed that NL_1488, RR_21 are the most stable lines in terms of yield ,with scores of -0.6239, -0.3652 (Table 4) respectively. PC1 score revealed that NL_1504, NL_1445, BL_5099, NL_1503 are relatively unstable line, scoring 0.7383, 0.5596, 0.5417, 0.5069 respectively. Conversely, PC2 score showed that Gautam, NL_1447, NL_1512 exhibit instability across all environment, scoring 0.51135, 0.401816, 0.15799 respectively.

In the AMMI biplot, 5 environments with the stability and adaptability of 20 genotype were illustrated. The wheat genotype that are assembled together exhibit similar performance across all the environments. The wheat line NL_1402, BL_4984, NL_1506 are closely grouped, indicating they perform similarly under both rainfed and irrigated conditions. The wheat line NL_1508, NL_1437, RR_21 are also closely grouped, indicating similar performance under drought and heat stress rainfed conditions. The wheat line BL_5116, BL_5106, NL_1512 fall under same regime indicating similar performance under heat stress irrigated and heat stress rainfed. NL_1437 was the most stable genotype as it has uniform yield across all the environments may be due to its high yielding parentage or better gene for abiotic stress tolerance (Fig 1). Conversely, genotypes NL_1504, NL_1501 and NL_1488 were relatively unstable in yield as these lines are far from the origin. Specifically, NL_1504, was well suited for irrigated conditions, while NL_1488, NL_1501 were specifically adapted to heat stress irrigated condition and Bhirkuti was adapted to heat stress rainfed.

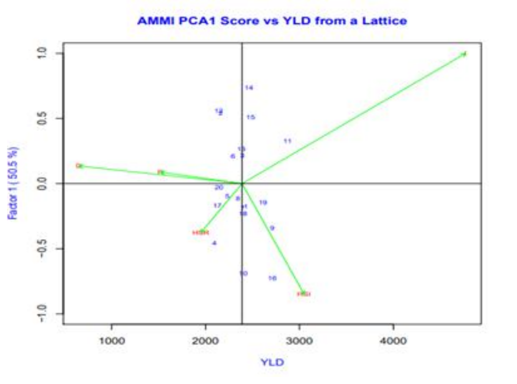
The most effective method for visualizing the interaction between genotype and environment is the polygon view of the biplot , specifically the which-won-where model (Poudel *et al.,* 2023b). As shown in Fig (2), the biplot was divided into 6 sectors where HIS, HSR, R, I, D environments fall. The vertex of each sector indicates the genotype with the highest yield in that particular environment. The genotypes farthest from the origin are connected to form the biplot polygon, which encloses the

Table 4: Interaction principal component of AMMI (PC1 and PC2) with the yield of 20 wheat genotypes.

Genotypes	Entry no.	PC1	PC2
BL_5106	1	-0.1732	-0.0923
BL_5099	10	-0.6912	-0.6239
BL_4984	11	0.32705	0.40182
Bhirkuti	12	0.55965	-0.1496
NL_1437	13	0.26404	-0.2386
NL_1402	14	0.73833	-0.1397
Gautam	15	0.5069	-0.1788
BL_5116	16	-0.729	-0.1655
NL_1492	17	-0.1689	-0.3652
NL_1488	18	-0.2321	0.15799
NL_1447	19	-0.1425	1
NL_1445	2	0.54179	-0.15
NL_1506	20	-0.0277	-0.1428
NL_1504	3	0.21649	-0.1051
NL_1503	4	-0.4581	0.02099
NL_1501	5	-0.0981	0.21326
RR_21	6	0.21013	-0.0893
NL_1512	7	-0.1876	0.51135
NL_1509	8	-0.1148	0.22136
NL_1508	9	-0.3413	-0.086
	D	0.13526	-0.2047
	HSI	-0.8491	0.75193
	HSR	-0.3743	-0.6896
	I	1	0.43371
	R	0.08886	-0.2913

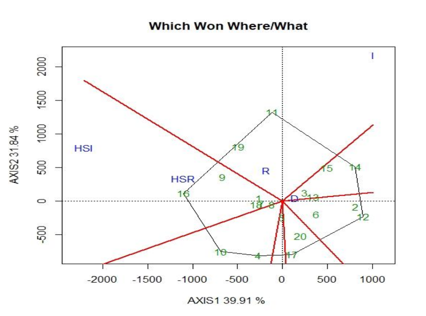
Table 5: ANOVA table of combined analysis.

	SS	PORCENT	PORCENAC	DF	MS	F Value
ENV	4.15E+08	91.62877	91.62877	4	1.04E+08	**
GEN	10285598	2.27039	93.89916	19	541347.3	*
ENV*GEN	27638693	6.10084	100	76	363667	*
PC1	13650131	51.81852	51.81852	22	620460.5	
PC2	7381007	28.01972	79.83824	20	369050.4	
PC3	4882060	18.53324	98.37148	18	271225.6	
Residuals	79997722			140	571412.3	



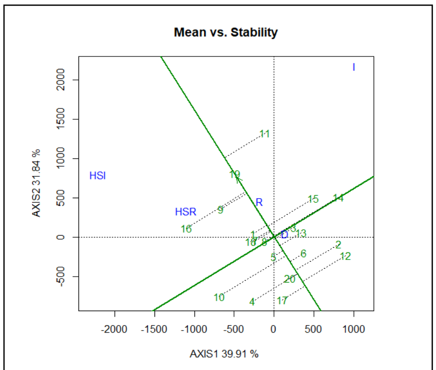
Where indication of genotypes 1-20 is present in Table 1.

Fig 1: AMMI biplot for yield.



Where indication of genotypes 1-20 is present in Table 1.

Fig 2: Biplot showing which-won-where.



Where indication of genotypes 1-20 is present in Table 1.

Fig 3: Mean vs stability.

remaining genotype. Genotypes falling in the vertex of polygon have greater performance in their specific environment where as genotypes near the origin exhibit the stability across all examined environments.

The genotype NL_1447 is the farthest from the origin and is the vertex line of this sector, implying that it is specifically adapted in the rainfed condition although it showed lower stability across all environment. Similarly, the sector representing terminal drought conditions includes NL_1504, which is highly responsive in this environment. Furthermore, NL_1504 is characterized by the longest distance from origin and is the vertex line of this sector indicating it as the most responsive in terminal drought environment. Thus, the which-won-where pattern revealed the line 11(NL_1447) as winning line in the rainfed condition while 14(NL_1504) as winning line in drought conditions. In addition, the polygon view showed NL_1404 is close to the biplot's origin, indicating consistent performance across all tested environments and making it the most stable genotype. Conversely, NL_1488, NL_1501, RR_21, NL_1445, NL_1504, NL_1447, NL_1509, Bhirkuti, NL_1503, BL_5099, NL_1508, NL_1492 are present in the sector without any test environment, indicating that they are poorly adopted to all the environments (Fig 2).

Where Indication of Genotypes 1-20 is present in table 1. The genotypes BL_5106, BL_1492, BL_5116and NL_1512 had above-average yields and were more stable whereas, NL_1447, NL_1503 also had above average yield but were less stable (Fig 3). Furthermore, NL_1437, NL_1402, NL_1508, NL_1306, RR_21 exhibited higher stability but had below average yield. NL_1445, BL_5099, Bhirkuti, NL_1488, were both below average yield with less stability. The most desirable genotype is one that is closest to the arrowhead and less distant from average conditions coordinates, indicating higher stability. This analysis showed that NL_1509 was the most stable genotype, followed by BL_5116, BL_5106, NL_1512, NL_1492 and NL_1503.

CONCLUSION

The study findings show varying percentage yield reductions under different stress conditions compared to irrigated ones: 36.07% for heat stress irrigated, 59.07% for heat stress rainfed, 86.37% for droughtand 68.12% for rainfed conditions, with the most significant yield loss occurring under drought conditions. Yield is notably influenced by genetics, environmentand their interactions. Genotype NL_1447 was best suited to irrigated conditions, NL_1509 to heat stress irrigated conditions, NL_1492 to rainfed conditionsand NL_1445 to drought conditions. NL_1501 was most suited to heat stress rainfed conditions. NL_1447 had the greatest distance from the origin in rainfed conditions. The "which won where" model identified NL_1447 as the winning line in rainfed conditions and NL_1504 in drought conditions. According to the mean vs. stability model, NL_1509 was the most stable genotype.

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Conflict of interest

The author declares there are no competing interests.

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